A Systems Approach for Investigating Water, Energy, and Food Scenarios in East-Central Maui

Carey W. King, Ph. D.

Energy Institute

&

Jackson School of Geosciences

November 2014

Table of Contents

Executive Summary

A Systems Approach for Investigating Water, Energy, and Food Scenarios in East-Central Maui

A report of The University of Texas at Austin to the Ulupono Initiative

Carey W. King, Ph.D.

The rain follows the forest (DLNR, 2011). From Hawaii's forest come streams that collect much of this rain, and the water in these streams enables much of the cultural, ecological, and economic value on the islands. Hawaii's future sustainability is linked to its use of water resources. The Island of Maui is certainly no different. In many ways, Maui exemplifies the need for Hawaii residents to consider how they will adapt to climatic and economic changes that originate both from within and from without the Hawaiian Islands.

The world's biophysical and climate systems are changing, in turn pressuring changes for adaptation in human socio-economic systems. Not only in Hawaii, but all over the world there is an increasing need to engage in as many coherent energy, water, and agriculture policies as are possible (King et al., 2013). Constraints in water resources can easily translate to constraints in energy and food production. To ensure Maui's long-term prosperity it is crucial to resolve Maui's societal conflicts focused on water. This report exists to provide information to the people of Hawaii such that they can facilitate further discussion as to their desired use of water in the context of a sustainable future for Hawaii.

This report seeks to inform actions for Hawaii's sustainable water use in agriculture on East Maui using a *systems approach*. This systems approach considers water as available for multiple purposes to consider how Maui's water resources can be used to achieve multiple sustainability objectives. From a water perspective, sustainability is narrowly defined as not drawing on groundwater beyond maximum sustainable yield. This report explicitly does not address the litigation issues related to instream flows and native uses of water. Ulupono commissioned this report to address the following questions:

- Is the current use of energy and water for agriculture sustainable?
- Do we have enough water to meet society's goals of increased local food and renewable energy production without causing unintended consequences?
- How much food and electrical and fuel energy can we produce from the East Maui watershed while sustainably stewarding our water resources?
- What are the impacts to the broader Maui water and energy systems?
- What do we know about how much can water supply be increased through watershed management and restoration and at what cost?

System Scenarios

The analysis described in this report focuses on ***the water and energy inputs and outputs for producing both biofuel feedstocks in the Central Plain of Maui and food crops in Upcountry Maui***. The system water, food, and energy scenarios in this report are based upon the idea that Maui's water supplies are becoming increasingly constrained due to changes in climate, increasing native and visitor populations, and movements and legal rulings to reduce water diversions from streams for both environmental and native cultural reasons (e.g. taro farming).

The water availability for different scenarios is based upon the precipitation, surface water, and groundwater on the Eastern (Haleakala) portion of Maui. Most of the 330 million gallons per day (MGD) of average surface water runoff is already used for some purpose (see **Figure E-1**). While there appears to be a large amount of groundwater resource available, the costs are prohibitive for accessing the bulk of that water. Many new water supplies such as more pipelines, groundwater wells, reclaimed water facilities, and desalination are constrained by the available capital required to invest in new fresh and potable water sources. There is some opportunity to reclaim more wastewater that is already being reclaimed. Two strategies (i) increased water conservation and demand management and (ii) increased wastewater treatment for reclaimed water use, have been determined to be the most promising options for matching Maui potable water demand with supply (see Section 3.2 and (DWS, 2010)).

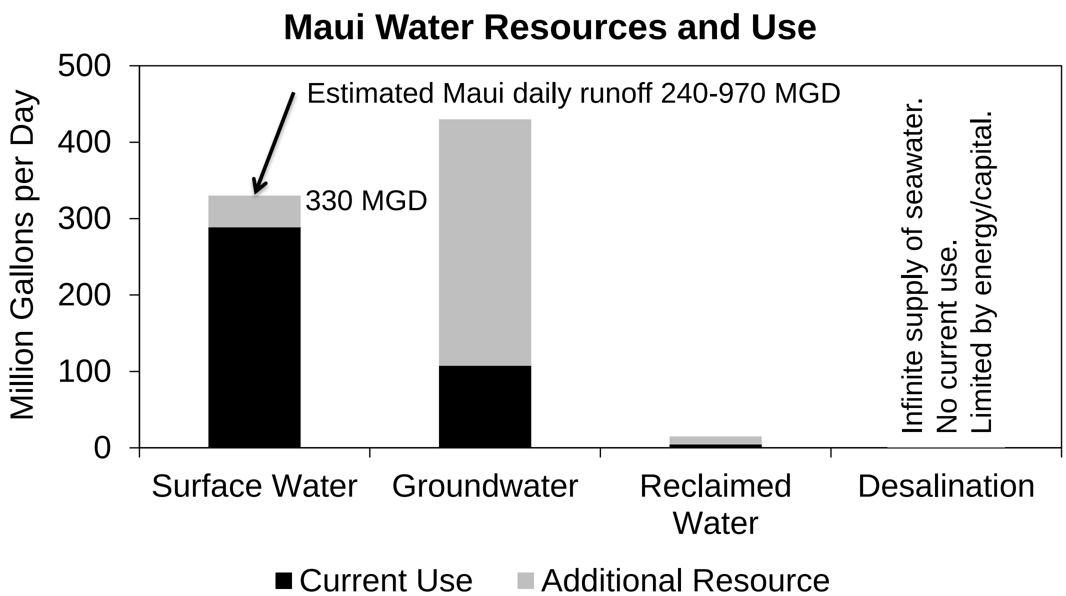

Figure E-1. Approximately 400 million gallons of water per day (MGD), on average, are used for irrigation and municipal supply on Maui. Reclaimed water potential supply from treated wastewater is ~15 MGD, and 20-30% of wastewater is in current use (Wastewater Community Working Group 2010). An estimated 330 million gallons of surface water are available for use each day (Kinoshita and Zhou 1999, Table 3-1). East Maui Irrigation capacity = 445 MGD. 10-40% of 70 in/yr of rain becomes surface water of ~240-970 MGD (Gingerich and Oki, 2000).

The scenarios presented in this report are structured to provide insight into the following questions about water, energy, and food on Maui:

- How does a smaller crop footprint (e.g. land use) for sugar cane relate to water use, groundwater sustainability, and yield?
- How much liquid biofuel can be produced from sugar cane, or other bioenergy feedstocks, in Central Maui?
- How do alternative biofuel crops compare in terms of water consumption?
- How much water and land are needed to grow a significant share of locally-consumed meat, dairy, fruits, and vegetables for Maui?
- How does a 'systems' combination of crops for biofuels and food relate to surface water use, groundwater sustainability, and broader sustainability goals for Hawaii and Maui?

The scenarios begin with a "calibration" scenario that models the current 'water-deficit' irrigation situation as described by Hawaiian Commercial and Sugar (HC&S) in Exhibit G-1 of (CWRM, 2010).

This calibration scenario verifies that the model can represent today's practice. Then, alternative scenarios are simulated on a smaller total crop footprint of 23,000 acres in Central Maui (eastern side) instead of the current 30,000 acres. Three alternative biofuel crops are modeled: sweet sorghum, cassava, and banagrass.

In addition to the biofuel scenarios, two food production scenarios are included. One food scenario is based on a concept of irrigated pasture for grass-fed cattle to produce both beef and milk (or other dairy products). *Milk and beef production serve as proxy indicators* for output of consumer products from use of pasture land. The second food scenario is for fruit and vegetable production, or "diversified agriculture". Thus, the food scenarios present one of many possible ways to utilize land on Maui for diary, protein, and fruit and vegetables. The scenarios are defined as follows:

<u>Calibration – 30,000 acres sugar cane, water deficit:</u> The calibration scenario assumes approximately 30,000 acres of sugar cane grown on current HC&S land using the average irrigation from Exhibit G-1 of (CWRM, 2010). Results are calculated for sugar and molasses production.

<u>Scenario 1 – 30,000 acres sugar cane, full water:</u> This scenario is the same as the calibration scenario, except groundwater pumping is increased to deliver the full water needs to the sugar cane crop. Results are calculated for ethanol production.

<u>Scenario 2 – 23,000 acres sugar cane, full water:</u> This scenario is a reduced footprint for sugar cane production to compare the water and yield to the calibration scenario and Scenario 1. Results are calculated for sugar and molasses production (Scenario 2s) and ethanol production (Scenario 2e).

<u>Scenario 3 – 23,000 acres sweet sorghum, full water:</u> This scenario is to compare sweet sorghum biofuel production and water needs to that of other biofuel crops.

<u>Scenario 4 – 23,000 acres cassava, full water:</u> This scenario is to compare cassava biofuel production and water needs to that of other biofuel crops. Two cassava yields are assumed: a 'standard' cassava yield (Scenario 4s) representative of existing commercial production, and an 'improved' higher cassava yield (Scenario 4i) believed possible by Ulupono Initiative.

<u>Scenario 5 – 23,000 acres banagrass, full water:</u> This scenario is to compare anticipated banagrass biofuel production and water needs to that of other biofuel crops.

<u>Scenario 6 – 5,850 acres pasture:</u> This scenario models beef and milk production from grass-fed cattle in Upcountry Maui.

<u>Scenario 7 – 1,000 acres diversified agriculture:</u> This scenario models fruit and vegetable production in Upcountry Maui.

<u>Scenarios 8 – System energy and food scenarios:</u> These four 'system' scenarios combine the results for Scenarios 6 and 7 to each of the biofuel Scenarios 2, 3, 4, and 5.

Water Resource Sustainability

In considering multiple uses of water on Maui, one measure of water resource sustainability is the balance of groundwater extraction and recharge. To use an aquifer sustainably, one must not continually extract more water from an aquifer than seeps in from rainfall and irrigation. The Department of Land and Natural Resources has established sustainable aquifer yields to help manage groundwater use (Wilson Okamoto Corporation, 2008).

As shown in previous studies, the irrigation of sugar cane in Central Maui enables groundwater extraction higher than that of the sustainable yields of the Kahului (1 million gallons per day, MGD, or 0.4 billion gallons per year, BGY) and Paia aquifers (7 MGD, or 2.5 BGY) because the surface irrigation water from the East Maui Irrigation system effectively recharges the aquifers. The leftmost results in Figure E-2 show that while 19 BGY of water is extracted to irrigate sugar cane, there is 18 BGY of recharge, leaving a net groundwater extraction of 1 BGY or less. However, the results of Scenario 1 show that irrigating the same 30,000 acres of sugar cane to fulfill all crop water needs creates a substantial net water depletion of 13 BGY due to the same quantity of East Maui Irrigation (EMI) system surface water but much more groundwater extraction (35 BGY). This result reinforces why, in an average rainfall year, 30,000 acres of sugar cane in Central Maui cannot be sustainably fully irrigated.

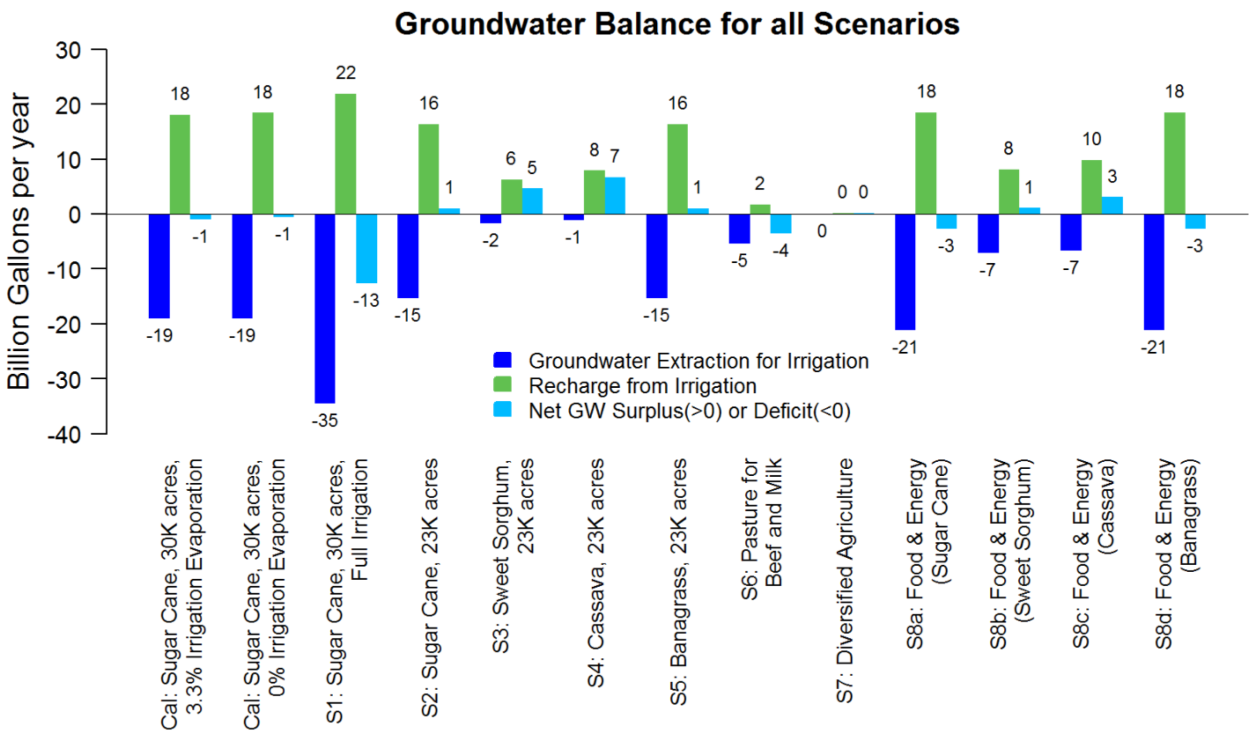

Figure E-2. The groundwater extraction, recharge from irrigation, and net groundwater extraction provide summary metrics to compare the groundwater sustainability of all scenarios. Plotted values assume average monthly rain and EMI ditch flows. Numbers might not add due to rounding.

Scenarios 2–5 show that growing biofuel crops on 23,000 acres in Central Maui enables full irrigation of each candidate crop while maintaining aquifer sustainability. Fully irritating 23,000 acres of sugar cane (Scenario 2) provides approximately the same total biomass yield as the current practice of partially irrigating 30,000 acres (calibration scenario). Growing cassava and sweet sorghum requires much less water, although the assumption of less water for sweet sorghum corresponds to a relatively low yield for Hawaiian conditions. The 5,850 acres of pasture in Upcountry Maui for intense beef and milk production would require significant irrigation (5 BGY), assumed to come solely from groundwater. The irrigation requirements for 1,000 acres of diversified agriculture are minimal compared to the other crops.

The four combined energy and food 'system' scenarios show net groundwater extraction that is either positive or well below the estimated sustainable yields for Central Maui and Upcountry aquifers (Paia, Kahului, and Makawao).

Energy and Food Sustainability

The energy and food production of the four 'system' scenarios can be viewed as relative to the total Maui consumption for those products. Figure E-3 shows how each of the system scenarios compare to the present "calibration" scenario of 30,000 acres of sugar cane for sugar. Each system scenario has the same production of milk (100% of Maui consumption), beef (41% of Maui consumption), and fruits and vegetables (69% of Maui consumption). The amount of gross electricity generated from renewable energy includes the biomass generation from the biofuel feedstocks as well as existing wind and hydropower generation on Maui. The renewable generation on Maui is now dominated by wind power, and all renewable sources range between 22% and 28% of the gross electricity generation on the island.

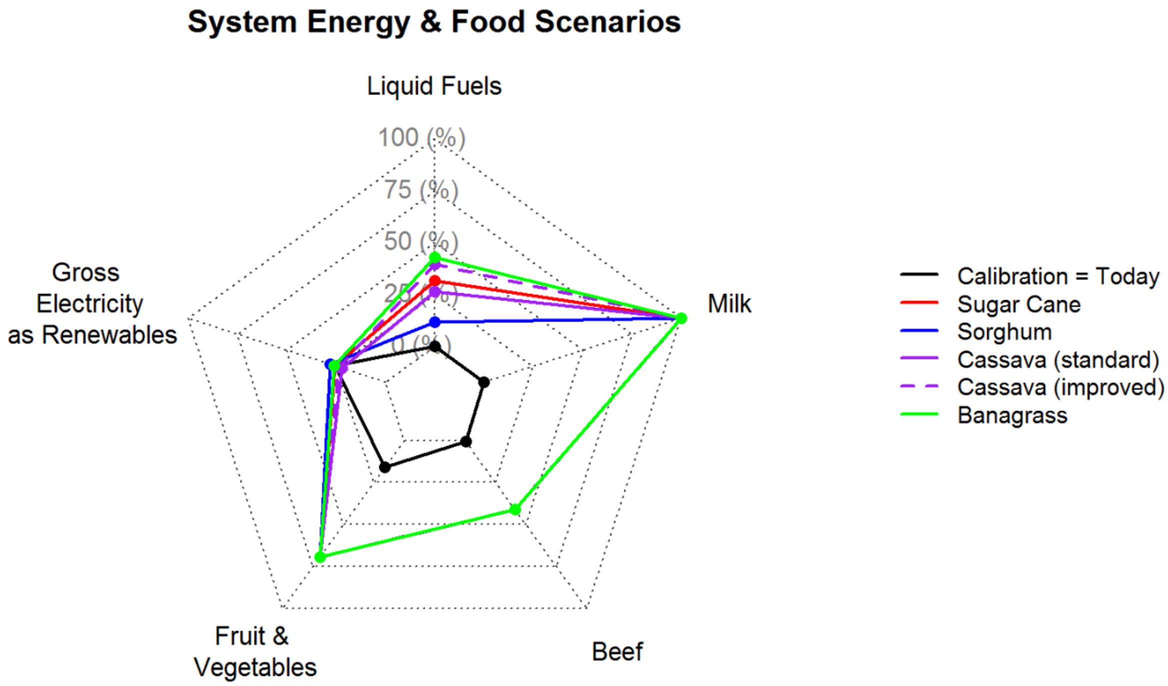

Figure E-3. Maui production relative to consumption for each of five metrics for the combined 'system' energy and food scenarios. All 'system' energy and food scenarios, by their definition, meet the same percentage of local milk, beef, and fruits & vegetables. The calibration scenario representing today's situation produces much less food and no biofuel.

The amount of liquid biofuels, ethanol in all cases, varies considerably among the scenarios. The percentage of liquid fuels is calculated as the energy content in ethanol divided by the energy content of Maui's gasoline consumption. Very little biofuel (12%) can be produced from sweet sorghum when assuming the low yields from recent Hawaii crop trials (Hashimoto, 2012, Hashimoto et al., 2012)). More extensive crop trial information is needed to verify if sweet sorghum can be grown in Hawaii with the same yields as non-tropical regions. Twenty-three thousand acres of sugar cane converted to ethanol could produce 32% of Maui's gasoline energy consumption, and approximately 43% could be produced from banagrass (using cellulosic materials). Ethanol production from cassava could range from 26% to 40% of Maui gasoline energy consumption depending upon how much the cassava yield could be increased from known 'standard' yields.

The water balance calculations were repeated when assuming the low ditch flow year of 1962 in which the EMI ditch system delivered approximately 28% less water than an average year. In this "drought" scenario the 23,000 acres of cassava is still modeled to have net groundwater recharge even when applying full irrigation. The 23,000 acre sugar cane and banagrass scenarios would operate at a substantial net loss of groundwater of 16 BGY relative to a 1 BGY net gain in an average ditch flow year.

Conclusion

Overall, there is a significant opportunity to meet multiple sustainability goals using the same or a lesser quantity of water for large-scale farming of biofuel crops in Central Maui. These multiple goals include more local food, increased renewable energy, and sustainable groundwater usage. Maui can create triple the economic value is gets from each gallon of water used in agriculture, while consuming one third less water than Central Maui uses today.

If less surface water is needed for agriculture in Central Maui, then 'newly available' surface water could be used for irrigating other lands for food production, the water could remain in streams for purposes of enhancing biodiversity cultural uses of water, and/or the water could be available to deal with potential reductions in future rainfall. The status quo agriculture in Central Maui currently operates at a water deficit with today's average rainfall patterns, but Hawaiian rainfall has been decreasing at a rapid rate the last few decades. These declines in rainfall are consistent with expectations from rising temperatures from climate change. Thus, there is the distinct possibility that Hawaiian rainfall will continue to decrease in the future. More drought-tolerant and less water-hungry crops are likely to be needed if only to deal with decreased rainfall, and increased water demands for municipal uses. By thinking systematically about water use on the island in short and long terms, Maui stakeholders have the potential to proactively adapt to a changing world such that they protect their most important and valuable resources.

More scientific and commercial research will be needed to definitively characterize the opportunities highlighted in this report before commercial agricultural companies or government could be confident in making the investments needed to change course. The critical needs for scientific and commercial research are:

- Watershed management and restoration to understand costs and hydrological impact
- Aquifer characterization, particularly for the major aquifers affected by ground water pumping and possible
- Pre-commercial bioenergy crop trials on cassava at the scale needed to affirmatively determine yield and harvest requirements
- Integration analysis of use of curtailed wind energy for water pumping in agriculture and municipal systems

If the same cooperative support from the Maui stakeholders that made this report possible extends to the next phase of inquiry, we are confident that Maui can realize the opportunities they collective have.